[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR SCHEDULING PACKET DATA TRANSMISSIONS IN A WIRELESS COMMUNICATION SYSTEM

(57) Abstract: A method (18) for scheduling packet data transmissions in a wireless communication system wherein a per-user Priority Function (PF) (24) is based on a channel condition indicated by a Rate Request Indicator (RRI). The method also considers fairness criteria dictated by predetermined Quality of Service (QOS) requirements. In one embodiment, the rate request indicator is a Data Rate Request (DRR). In another embodiment, rate request indicator is Carrier-to-Interference (C/I) information. In the exemplary embodiment, the base station calculates a Priority Function (PF) for the multiple mobile users. Each PF is a function of the rate request indicator and the projected throughput of a given mobile user. The PF values allow the base station to schedule active mobile units having pending data. The scheduling produces an approximately equal share of the allocated transmission time to the multiple mobile stations.

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METHOD AND APPARATUS FOR SCHEDULING PACKET DATA TRANSMISSIONS IN A WIRELESS COMMUNICATION SYSTEM

FIELD

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The present invention relates to wireless data communication. More particularly, the present invention relates to a novel and improved method and apparatus for scheduling packet data transmissions in a wireless 10 communication system.

BACKGROUND

In a wireless communication system, a base station communicates 15 with multiple mobile users. Wireless communications may include low delay data communications, such as voice or video transmissions, or high data rate communications, such as packetized data transmissions. U.S. Patent Application No. 08/963,386, entitled "METHOD AND APPARATUS FOR HIGH RATE PACKET DATA TRANSMISSION," filed Nov. 3, 1997 20 describes high rate packet data transmissions, and hereby expressly incorporated by reference.

Packet data transmissions are not required to be low latency transmissions, and therefore allow the base station flexibility in scheduling mobile user transmissions within a system. Once scheduled, the base station 25 may transmit data to as little as a single mobile user during a given time period. In general, scheduling of packet data mobile users in a system has two goals. The first goal is to optimize the utilization of each channel. The second goal is to allocate transmissions to mobile users fairly. The two goals sometimes compete. For example, channel quality conditions and the 30 amount of pending data for a given user may result in excessive time allocations to that user particularly at the expense of other users.

There is a need, therefore, for a fair method for scheduling packet data transmissions to mobile users that is channel-sensitive.

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SUMMARY

The disclosed embodiments provide a novel and improved method for scheduling packet data transmissions in a wireless communication system. In one aspect, in a wireless communication system adapted for packet data transmissions, a method includes receiving rate request indicators for a plurality of mobile stations, calculating priority function values for the plurality of mobile stations in response to the rate request indicators, and scheduling transmissions to the mobile stations according to the priority function value.

According to another aspect, a wireless apparatus includes a priority factor calculation unit adapted to receive data rate requests from mobile stations and generate power factor values in response, and a scheduling unit coupled to the priority factor calculation unit, the scheduling unit adapted to schedule data transmissions.

According to still another aspect, a method for scheduling packet data transactions in a wireless communication system includes determining a pool of users, calculating a priority function of at least a portion of the pool of users, scheduling a first set of users having pending data transactions from the portion of the pool of users, receiving rate request indicators from the portion of the pool of users, and updating priority functions of the first set of users in response to the rate request indicators.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the presently disclosed method and apparatus will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. 1 illustrates in block diagram form a wireless communication system according to one embodiment;

FIG. 2 illustrates in flow diagram form a method for scheduling packet data transmission in a system as in FIG. 1 according to one embodiment;

FIG. 3 illustrates in block diagram form a base station as in FIG. 1 according to one embodiment; and

5   FIG. 4 illustrates in block diagram form a portion of a base station as in FIG. 3 according to one embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

10   In an exemplary embodiment of the present invention, a base station of a spread-spectrum wireless communication system schedules packet data transmissions to mobile users based upon the instantaneous values of a per-user Priority Function (PF). The user scheduling priority is related to the PF value, wherein a high PF value indicates a high scheduling priority and a low PF value indicates a low priority. In one aspect, a method for determining PF values is based on a channel condition indicated by a Rate Request Indicator (RRI). The method also considers a fairness criteria dictated by the Quality Of Service (QOS) requirements. Such a method provides robust protection against non-zero buffer under-runs on the transmitter side. In one embodiment, the rate request indicator is a Data Rate Request (DRR). In another embodiment, the rate request indicator is Carrier-to-Interference (C/I) information. Alternate embodiments may implement other types of rate request indicators or predictors. In the exemplary embodiment, the base station calculates a Priority Function (PF) for the multiple mobile users. Each PF is a function of the rate request indicator and the projected throughput of a given mobile user. The PF values allow the base station to schedule active mobile units having pending data. The scheduling produces an approximately equal share of the allocated transmission time to the multiple mobile stations.

30   Scheduling allocation improves channel sensitivity by reducing adverse effects associated with assigned data rates. Actual data rate assignments provide quantized transmission rates. This results in a coarse adjustment of data rates within a system. Actual data rates may be truncated,

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or otherwise manipulated, to conform to the assigned and available data rates. By using a rate request indicator to determine a transmission data rate, the data rate is adjusted according to the actual requirements and operating environment of the system.

5   In an exemplary embodiment illustrated in FIG. 1, a wireless communication system 10 includes a base station 12 that communicates with mobile stations 14 and mobile stations 16 via an air interface or radio link. The base station 12 processes separate transmissions for each of mobile stations 16. As illustrated, mobiles stations 14 are employing low delay data

10   communication type services, such as voice communications, while mobile stations 16 are employing high rate packet data communications. Communications between base station 12 and mobile stations 14 are performed in real-time and therefore all active communications are performed simultaneously and concurrently. In contrast, packet data

15   communications with mobile stations 16 may be scheduled, wherein communications to multiple mobile stations 16 are transmitted simultaneously at a given time. Alternate embodiments may allow concurrent transmissions to more than one of mobile stations 16 seeking to optimize channel utilization.

20   FIG. 2 illustrates a method 18 for scheduling mobile stations 16 within system 10. The process begins by determining a pool of active mobile users within system 10 at step 20. The total number of mobile stations 16, or users, in the pool is designated as "N." If N is equal to 0, at step 22, the process ends, else the process continues to step 24 to calculate a PF for each of a

25   subset of "M" users within the pool, wherein the M active users have data pending. The PF calculation is performed according to the following equation:

$$PF(j) = \frac{DRR(j)}{T(j)}, \text{ for } j=1, \ldots, M, \tag{1}$$

wherein j is a user index corresponding to the M active users with pending

30   data. In the exemplary embodiment, a rate request indicator is implemented as DRR(j), the Data Rate Request (DRR) received from user j, for j=1, ..., M. Having the channel-sensitive rate request indicator in the numerator

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provides proportionality to the scheduling of users in system 10. The rate
request indicator is then divided by a projected throughput associated with
each user j, $T'(j)$. The actual throughput of each user, j, may be represented
as $T(j)$, although the actual throughput is not used directly in this
5   calculation of Equation (1).

From the subset of M active users with data pending, at step 26, a
further subset is determined of "K" users to be scheduled for transmission.
In the exemplary embodiment, the subset of K users is determined according
to system configuration and a predetermined scheduling policy. Often K = 1,
10   or K is constrained to a single user. However, K may be any number less
than or equal to M.   Based on the calculated PF values, the base station
schedules "K" users at step 28. Note that the K scheduled users constitute a
subset of the N active users, i.e., ($K \leq M \leq N$). The base station 12 then
transmits packet data transmissions at step 30 according to the schedule of
15   step 28.   Transmission involves determination of transmission power,
power control, data rate, modulation, and other parameters of transmission.
Note that concurrently, the base station 12 may be transmitting low latency
transmissions to mobile stations 14.

At step 32, the base station 12 updates each projected throughput T' ,
20   for each of the K scheduled users as a function of a corresponding rate
request indicator received from each scheduled user. The following formula
describes the T' update calculation for scheduled users according to the
exemplary embodiment:

$$T'(j,n+1) = (1-\alpha) \cdot T'(j,n) + \alpha \cdot DRR(j) \quad , \tag{2}$$

25   wherein α is a time constant of a smoothing filter used for scheduling, for
digital samples having index n. In one embodiment, the time constant may
be related to the targeted QOS and/or velocity of each mobile station 16. In
the exemplary embodiment, a rate request indicator is implemented as
DRR(l), the Data Rate Request (DRR) received from user l , for l=1, ..., N.
30   Having the channel-sensitive rate request indicator in the numerator
provides proportionality to the scheduling of users in system 10. The rate
request indicator is then divided by a projected throughput associated with

each user j, $T'(j)$. The actual throughput of each user, j, may be represented as$T(j)$, although the actual throughput is not used directly in this calculation of Equation (1). Rather, the scheduling method makes a prediction or projection of the throughput of each user based on the rate request indicator received from that user. The rate request indicator may be the DRR transmitted via a Data Rate Control (DRC) channel, wherein the user determines a quality of the transmission channel and determines a corresponding data rate to request. The quality of the transmission channel may be a C/I measure of transmissions received by the user, wherein a corresponding DRR is associated with the C/I ratio, such as via a lookup table. In one embodiment, the user sends the C/I ratio to the base station 12 and the base station 12 determines a data rate based on the C/I. Alternately, the user may determine the data rate to request based on errors in transmitted data received by the user. The user may use a variety of methods to determine a data rate to request of the base station. Similarly, the user may implement a variety of rate request indicators for requesting a data rate from the base station. Still further, in one embodiment, different mobile stations 16 implement different rate request indicators.

If $K < M$ at step 34 processing continues to step 36 to update each T' for non-scheduled users within the pool of N active users, *i.e.*, users not included in the M scheduled users. The projected throughput calculation for non-scheduled users is given as:

$$T'(i, n+1) = (1 - \alpha) \cdot T'(i, n) , \qquad \qquad - \qquad (3)$$

for i=1,..., (M-K). Here the rate request indicator is assumed to be zero for calculation of the projected throughput used for updating each PF associated with non-scheduled users.

The updated projected throughput values are used to update PF values. Processing then returns to step 26 wherein the updated PF values are used to continue scheduling any users that still have pending data.

The exemplary embodiment updates the PF values for each user as if each mobile station 16 always has sufficient amount of pending data, and that the rate requested by each mobile station 16 is realizable. Therefore, the

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scheduling sequence generated by the PF computed as in Equations (1)-(3) is not sensitive to any unpredictable states of the transmission buffers as long as a buffer has at least one bit of data to send.

5   FIG. 3 further details base station 12, including signals received, processed, and transmitted. As illustrated, base station 12 receives a rate request indicator, such as DRR or C/I, from multiple mobile stations 16. Control information is received from at least the mobile stations 16, and also may be received from a central controller, such as a Base Station Controller (BSC) (not shown). The base station receives traffic, referred to as "backbone

10   traffic," from a network (not shown), such as the Internet. In response to these signals, base station 12 transmits data to mobile stations 16.

FIG. 4 further details a scheduler portion of base station 12. Base station 12 includes a pool calculation unit 40 for determining the number and identification of mobile stations 16 active at a given time. Active mobile

15   stations 16 communicate with base station 12, but may not have any pending data transactions. The pool calculation unit 40 receives control information from the mobile stations 16 and the BSC (not shown), and also receives traffic from a network (not shown). In response, the pool calculation unit 40 provides user identification information, User ID(l) for l=1, ..., N, to a PF

20   calculation unit 42. The user identification information is provided for all N active users in system 10.

The PF calculation unit 42 receives data rate request indicators from the mobile stations 16, such as DRR(l). The PF calculation unit 42 uses the rate request indicator to determine a PF for each user according to Equation

25   (1). The PF(j) for all users having pending data j=1, ..., K are provided to a scheduling unit 46. The scheduling unit 46 determines a schedule among the various users associated with PF(j). The scheduling unit 46 provides the schedule information to transmit circuitry 48. DATA IN is also provided to transmit circuitry 48, which transmits the data according to the schedule

30   information to produce DATA OUT. The schedule information is also provided to a calculation unit 50 which updates the projected throughput of the active N users. The scheduled users are updated according to Equation

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(2), while the non-scheduled users are updated according to Equation (3). For updating the projected throughput values, the calculation unit 50 receives rate request indicators for mobile stations 16. The updated projected throughput values for the subset of M users with pending data are then
5   provided back to the PF calculation unit 42 to update the PF values. The calculation unit 50 includes a smoothing filter, such as an Infinite Impulse Response (IIR) filter. The tap coefficients for the smoothing filter are configurable.

In one example, a mobile station 16 has a velocity of 3 km/hr and
10 experiences a doppler frequency, $f_{doppler}$, of 5.4 Hz. Projected throughput(s) are subject to IIR smoothing filtering according to Equations (2) and (3) with a time constant, T_W, given as approximately, is 2 sec. The IIR filter tap coefficient, α, is related to time constant T_W by a relation given as:

$$\alpha = \frac{1}{T_W \cdot \left(\dfrac{frames}{sec.} \right)}, \qquad (4)$$

15 resulting in a time constant of 1/100 given a frame duration of 20msec., *i.e.*, 50 frames/sec. In general calculation of α involves first determining a quality of service for the transmissions reflecting a fairness constraint wherein each mobile station 16 is allocated a time fraction within a predetermined tolerance. The calculation then optimizes α to achieve
20 optimum real system throughput.

Thus, a novel and improved method and apparatus for scheduling packet data transmissions in a wireless communication system has been described. Those of skill in the art would understand that the data, instructions, commands, information, signals, bits, symbols, and chips that
25 may be referenced throughout the above description are advantageously represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection
30 with the embodiments disclosed herein may be implemented as electronic

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hardware, computer software, or combinations of both. The various illustrative components, blocks, modules, circuits, and steps have been described generally in terms of their functionality. Whether the functionality is implemented as hardware or software depends upon the

5   particular application and design constraints imposed on the overall system. Skilled artisans recognize the interchangeability of hardware and software under these circumstances, and how best to implement the described functionality for each particular application.

As examples, the various illustrative logical blocks, modules, circuits,

10 and algorithm steps described in connection with the embodiments disclosed herein may be implemented or performed with a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components such as, *e.g.,*

15 registers and FIFO, a processor executing a set of firmware instructions, any conventional programmable software module and a processor, or any combination thereof designed to perform the functions described herein. The processor may advantageously be a microprocessor, but in the alternative, the processor may be any conventional processor, controller,

20 microcontroller, or state machine. The software modules could reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. The processor may reside in an ASIC (not shown). The ASIC may reside in a telephone (not shown). In the

25 alternative, the processor may reside in a telephone. The processor may be implemented as a combination of a DSP and a microprocessor, or as two microprocessors in conjunction with a DSP core, etc.

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention.

30 The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the

embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

WE CLAIM:

CLAIMS

1.   In a wireless communication system adapted for packet data
2   transmissions, a method comprising:
        receiving rate request indicators for a plurality of mobile stations;
4   calculating priority functions for the plurality of mobile stations in
                response to the rate request indicators; and
6   scheduling transmissions to the mobile stations according to the
                priority functions.

2.   The method of claim 1, further comprising:
2   calculating projected throughput values for the plurality of mobile
                stations as a function of the rate request indicators; and
4   updating the priority functions in response to the projected
                throughput values.

3.   The method of claim 2, wherein each priority function is calculated as
2   a rate request indicator divided by a projected throughput value for each of
    the plurality of mobile stations.

4.   The method of claim 1, wherein each of the rate request indicators is a
2   data rate request received from one of the plurality of mobile stations.

5.   The method of claim 1, wherein each of the rate request indicators is a
2   carrier-to-interference ratio received from one of the plurality of mobile
    stations.

6.   The method of claim 1, further comprising:
2   transmitting data to the plurality of mobile stations in response to
                scheduling transmissions.

7.   The method of claim 1, further comprising:

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2   updating the priority functions of scheduled mobile stations as a
           function of the rate request indicator.

8.   The method of claim 7, comprising:

2   updating the priority functions of non-scheduled mobile stations
           assuming the rate request indicator is equal to zero.

9.   A wireless apparatus, comprising:

2   a priority factor calculation unit adapted to receive data rate requests
           from mobile stations and generate power factor values in

4   response; and
           a scheduling unit coupled to the priority factor calculation unit, the

6   scheduling unit adapted to schedule data transmissions.

10.   The wireless apparatus of claim 9, further comprising:

2   a throughput calculation unit coupled to the scheduling unit and adapted to
      receive data rate requests from mobile stations and generate projected

4   throughput values as a function of the data rate requests,

      wherein the priority factor calculation unit is adapted to update priority

6   factor values based on the projected throughput values.

11.   The wireless apparatus of claim 10, wherein the throughput

2   calculation unit comprises a smoothing filter.

12.   The wireless apparatus of claim 11, wherein the smoothing filter is an

2   Infinite Impulse Response filter.

13.   The wireless apparatus of claim 10, wherein the throughput

2   calculation unit is adapted to generate projected throughput values for non-
      scheduled mobile stations assuming the rate request indicator is equal to

4   zero.

14. A method for scheduling packet data transactions in a wireless
2 communication system, comprising:

determining a pool of users;
4 calculating a priority function of at least a portion of the pool of users;

scheduling a first set of users having pending data transactions from
6 the portion of the pool of users;

receiving rate request indicators from the portion of the pool of users;
8 and

updating priority functions of the first set of users in response to the
10 rate request indicators.

15. The method of claim 14, further comprising:
2 updating a second set of users within the portion of the pool of users
different from the first set of users using a rate request of zero.

16. The method as in claim 14, wherein the portion of the pool of users
2 are users having pending data.

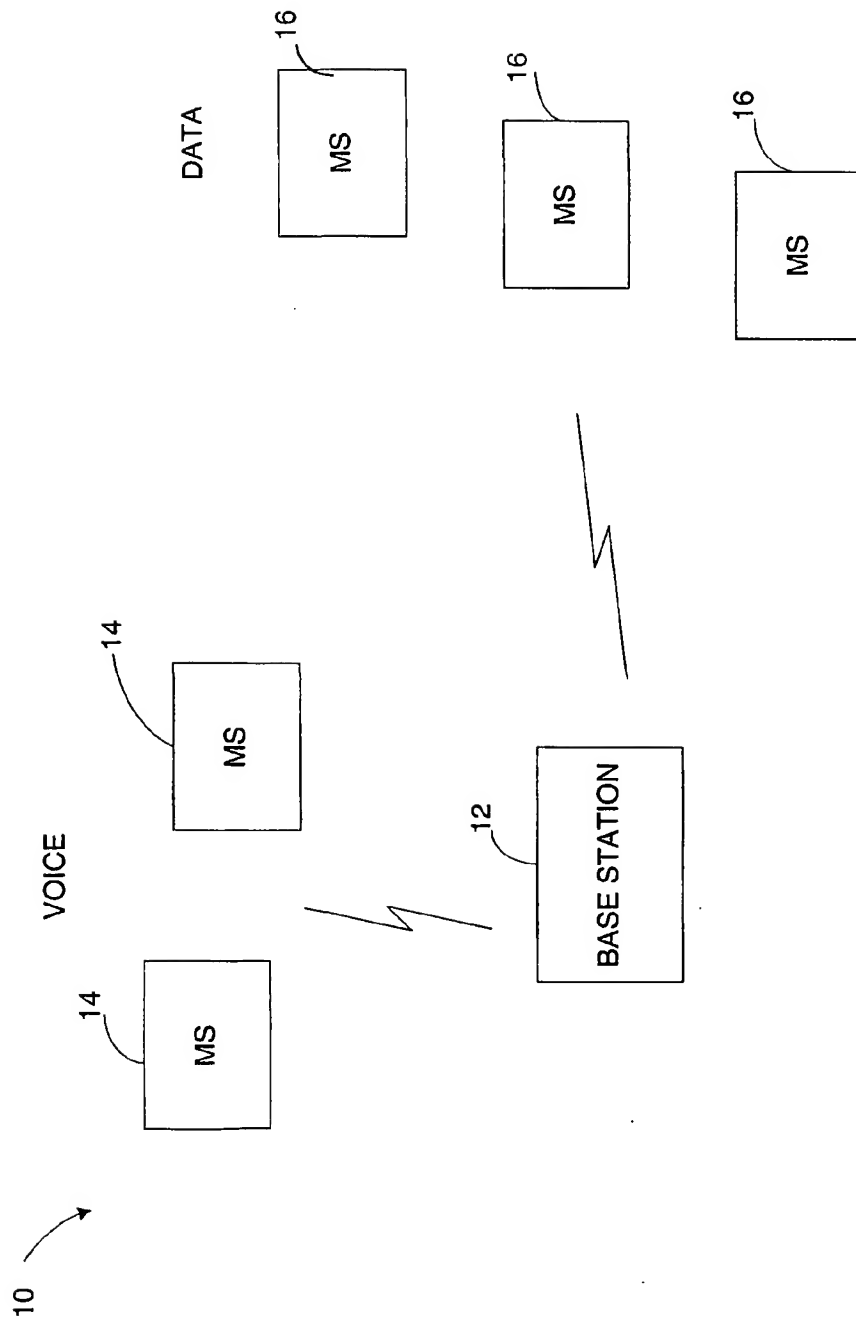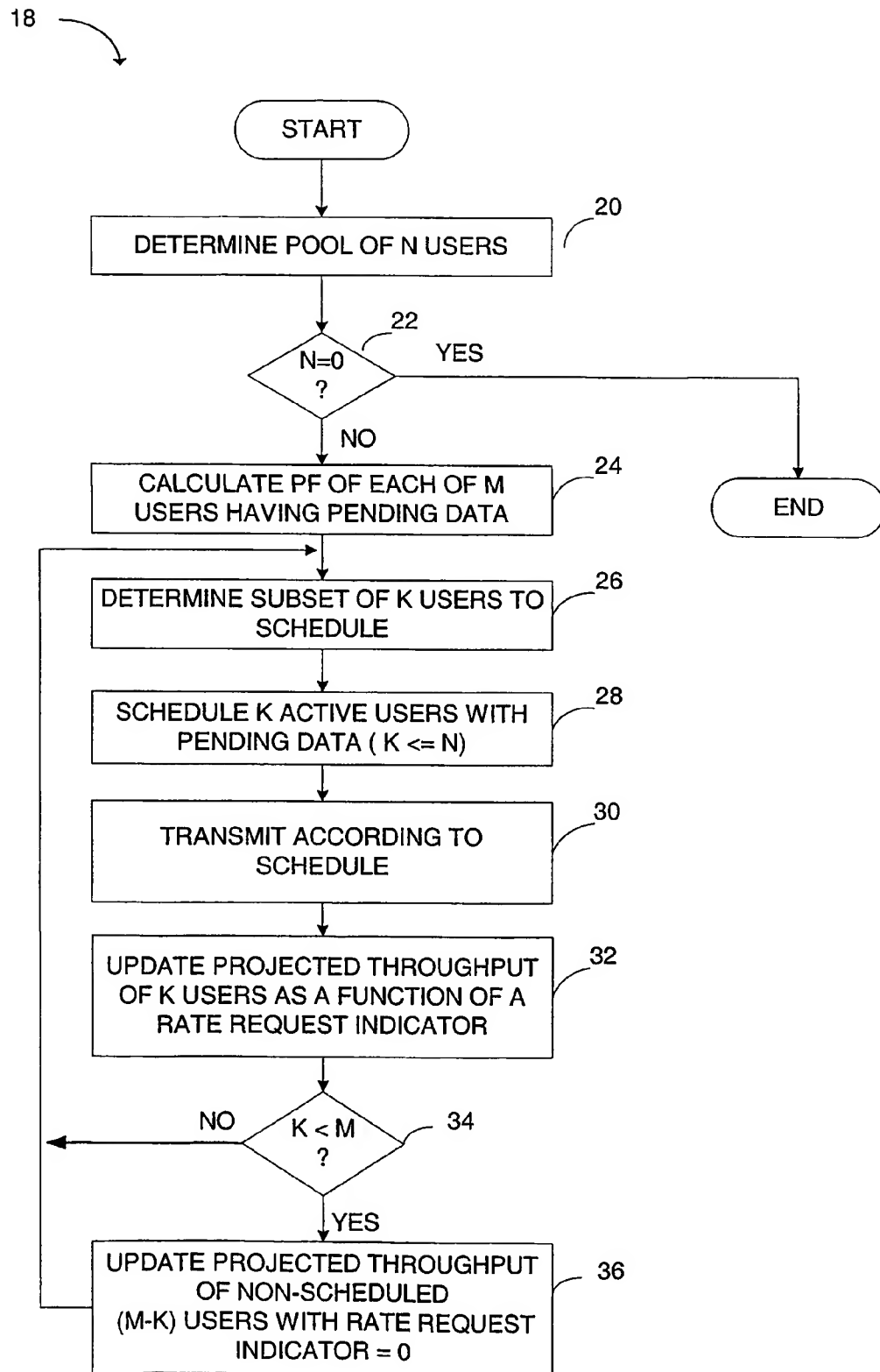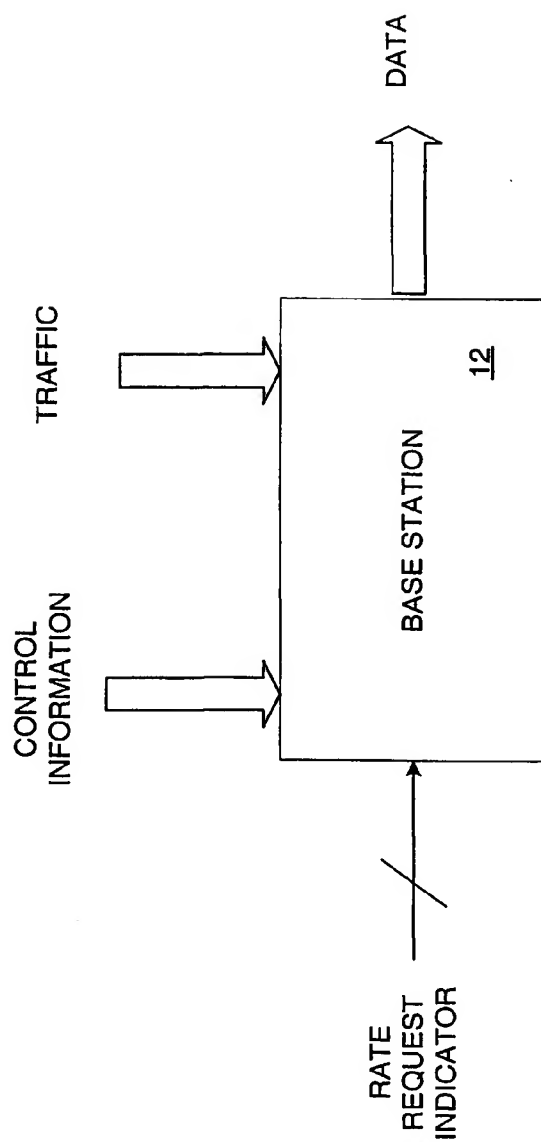17. The method as in claim 16, wherein the first set of users comprises
2 one user.

FIG. 1
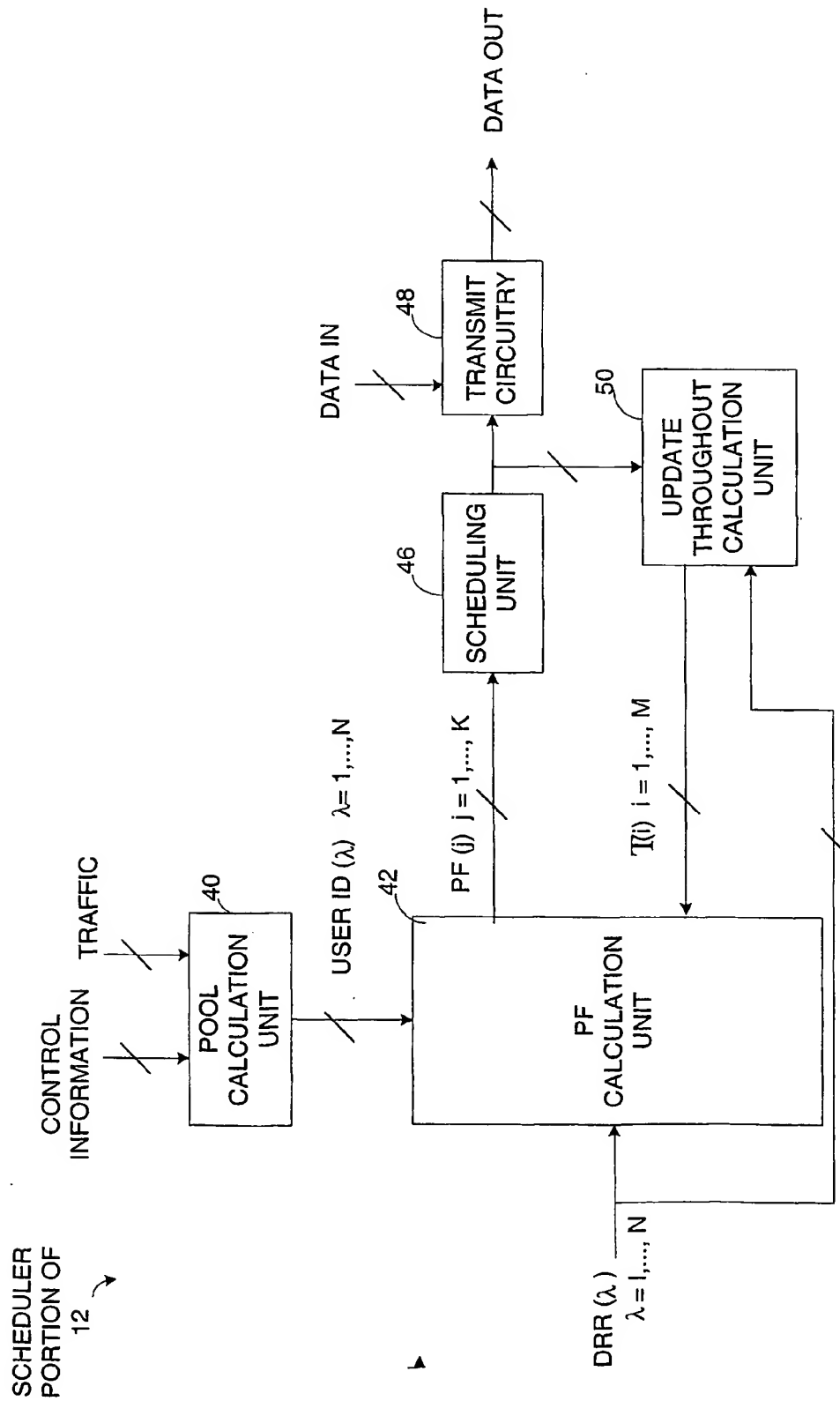
18

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                    ┌─────────────┐
                    │    START    │
                    └─────────────┘
                           │
                           ▼
              ┌──────────────────────────┐      20
              │ DETERMINE POOL OF N USERS │
              └──────────────────────────┘
                           │
                           ▼
                        ╱──────╲          22
                       ╱  N=0   ╲   YES
                       ╲   ?    ╱─────────────────────┐
                        ╲──────╱                      │
                           │                          │
                          NO                          ▼
                           │                    ┌──────────┐
                           ▼                    │   END    │
              ┌──────────────────────────┐  24  └──────────┘
              │ CALCULATE PF OF EACH OF M │
              │ USERS HAVING PENDING DATA │
              └──────────────────────────┘
                           │
          ┌────────────────┤
          │                ▼
          │   ┌──────────────────────────┐  26
          │   │ DETERMINE SUBSET OF K     │
          │   │ USERS TO SCHEDULE         │
          │   └──────────────────────────┘
          │                │
          │                ▼
          │   ┌──────────────────────────┐  28
          │   │ SCHEDULE K ACTIVE USERS   │
          │   │ WITH PENDING DATA (K <= N)│
          │   └──────────────────────────┘
          │                │
          │                ▼
          │   ┌──────────────────────────┐  30
          │   │ TRANSMIT ACCORDING TO     │
          │   │ SCHEDULE                  │
          │   └──────────────────────────┘
          │                │
          │                ▼
          │   ┌──────────────────────────┐  32
          │   │ UPDATE PROJECTED THROUGHPUT│
          │   │ OF K USERS AS A FUNCTION OF│
          │   │ A RATE REQUEST INDICATOR   │
          │   └──────────────────────────┘
          │                │
          │                ▼
          │      NO      ╱──────╲    34
          │◄────────────╱  K < M ╲
          │             ╲   ?    ╱
          │              ╲──────╱
          │                │
          │               YES
          │                ▼
          │   ┌──────────────────────────┐  36
          │   │ UPDATE PROJECTED THROUGHPUT│
          │   │ OF NON-SCHEDULED           │
          │   │ (M-K) USERS WITH RATE      │
          │   │ REQUEST INDICATOR = 0      │
          └───└──────────────────────────┘
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FIG. 2

FIG. 3

4/4

FIG. 4

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(54) Title: METHOD AND APPARATUS FOR SCHEDULING PACKET DATA TRANSMISSIONS IN A WIRELESS COMMUNICATION SYSTEM
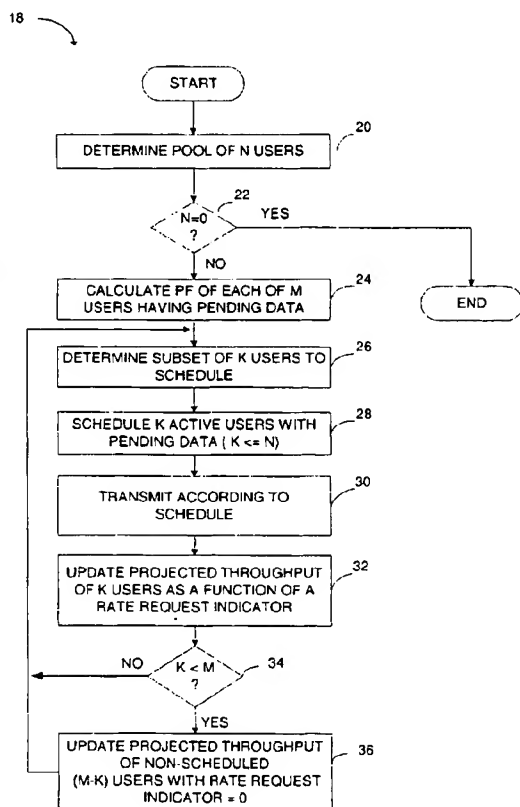
(57) Abstract: A method (18) for scheduling packet data transmissions in a wireless communication system (10) wherein a per-user Priority Function (PF) (24) is based on a channel condition indicated by a Rate Request Indicator (RRI). The method also considers fairness criteria dictated by predetermined Quality of Service (QOS) requirements. In one embodiment, the rate request indicator is a Data Rate Request (DRR). In another embodiment, rate request indicator is Carrier-to-Interference (C/I) information. In the exemplary embodiment, the base station calculates a Priority Function (PF) for the multiple mobile users. Each PF is a function of the rate request indicator and the projected throughput of a given mobile user. The PF values allow the base station (12) to schedule active mobile units (16) having pending data. The scheduling produces an approximately equal share of the allocated transmission time to the multiple mobile stations (16).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7   H04L12/56

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   H04Q   H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 00 25483 A (RUUTU JUSSI ;KILKKI MATTI K (US)) 4 May 2000 (2000-05-04) page 4, line 21 - line 30 page 5, line 16 - line 19 page 10, line 1 -page 11, line 8 page 20, line 6 - line 16 ---	1,4-7,9, 14,16,17
X	US 5 996 019 A (BUBENIK RICHARD G ET AL) 30 November 1999 (1999-11-30) abstract ---	1,9,14
P,X	WO 01 71926 A (QUALCOMM INC) 27 September 2001 (2001-09-27) the whole document ---	1-17
A	WO 98 59523 A (TANTIVY COMM INC) 30 December 1998 (1998-12-30) abstract ---	1-17

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X	Further documents are listed in the continuation of box C.	X	Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
16 January 2003	28/01/2003

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